Safety Critical Structures Data Package

Fluids and Combustion Facility
Fluids Integrated Rack

Rev. 1
Preliminary
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AUTHORIZED by CM when under FORMAL Configuration Control	
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PREFACE

The National Aeronautics and Space Administration (NASA) is developing a modular, multi-user experimentation facility for conducting fluid physics and combustion science experiments in the microgravity environment of the International Space Station (ISS). This facility, called the Fluids and Combustion Facility (FCF), consists of three test platforms: the Fluids Integrated Rack (FIR), the Combustion Integrated Rack (CIR), and the Shared Accommodations Rack (SAR). This document presents an overview of the structural analysis performed on FIR prior to the Preliminary Design Review (PDR).

The FIR structures fundamental frequency is well above 35 Hz. All Safety Critical Structures analyzed were shown to have positive Margins of Safety. Fail Safe analyses of the safety critical fasteners were found to be Non Fracture Critical.

SAFETY CRITICAL STRUCTURES DATA PACKAGE
FOR THE
FLUIDS AND COMBUSTION FACILITY
FLUIDS INTEGRATED RACK

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REVISION PAGE
FIR SAFETY CRITICAL STRUCTURES DATA PACKAGE

Revision	Date	Description of Change or ECO's Incorporated	Verification and Date
Preliminary	10/17/00	Initial	10/20/00
Rev. 1	12/18/00	Revised Section 1.1 per NASA review	12/21/00

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1.0 INTRODUCTION

1.1 Scope.

This data package will summarize FIR's structural design criteria, its safety critical structures, material properties, the finite element model, mass properties, modal analysis, design load factors, stress analysis, and fracture analysis. The modeling efforts will be useful in defining FIR's structural properties and its orientation within the ISPR; i.e., locations of primary attachments to the ISPR, stiffness, and mass. Margins of safety will be used to identify safety critical structures requiring additional stiffness or structures that can tolerate a mass reduction.

The analysis presented here are based solely on Launch configuration. The impact of temperature variation which may take place while FIR is on orbit will be determined in the future. The FIR design is currently undergoing a thermal redesign effort that will impact the unducted bench structure analyzed in this report. The structural analysis will have to be updated for the new ducted bench design.

Structural analyses for the proposed common system hardware; ATCU, Doors, EPCU, IOP, and Slides, is not covered within this report. The common systems are currently being designed for applications within CIR, FIR, and SAR. Structural analysis of this common hardware will be covered in separate reports. A detailed analysis report of ATCU and other common systems are being presented in CIR Safety Critical Structures Data Package (CIR-DOC-0065). However, included in this report, are the preliminary structural analyses of the primary structural attachments (fasteners and brackets) to the ISPR for these common hardware systems.

1.2 Purpose.

This document presents an overview of the structural analyses performed on FIR prior to the Preliminary Design Review (PDR). The structural analyses were based on the design requirements of SSP 41017, SSP 57000, SSP 57007, and NASA-STD-5001 in order to satisfy the payload verification requirements of NSTS 14046 and the safety requirements of NSTS 1700-7B and NSTS 1700-7B ISS Addendum. All Safety Critical Structures were analyzed and margins of safety determined in accordance to the guidelines of SSP 52005 and NSTS 08307.

2.0 DOCUMENTS

This section lists specifications, models, standards, guidelines, handbooks, and other special publications. These documents have been grouped into two categories: applicable documents and reference documents.

2.1 Order of precedence for documents.

In the event of a conflict between this document and other documents referenced herein, the requirements of this document shall apply. In the event of a conflict between this document and the contract, the contractual requirements shall take precedence over this document. All documents used, applicable or referenced, are to be the issues defined in the Configuration Management (CM) contract baseline. All document changes, issued after baseline establishment, shall be reviewed for impact on scope of work. If a change to an applicable document is determined to be effective and contractually approved for implementation, the revision status will be updated in the CM contract baseline. The contract revision status of all applicable documents is available by accessing the CM database. Nothing in this document supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.2 Applicable documents.

The documents in these paragraphs of the latest revision or issue are applicable to the FCF Project to the extent specified herein.

SSP 57000 Rev. E, 2/4/2000	Pressurized Payloads Interface Requirements Document International Space Station Program
SSP 52005 Rev. B, 12/10/1998	Payload Flight Equipment Requirements and Guidelines for Safety-Critical Structures International Space Station Program
SSP 57007 Rev. A Draft, 10/6/1998	International Standard Payload Rack (ISPR) Structural Integrator’s Handbook
SSP 41017, Part 2 Rev. F, 11/13/98	Rack to Mini Pressurized Logistics Control Module Interface Control Document (ICD) International Space Station Program
NSTS 08307 Rev. A, 7/6/1998	Criteria for Preloaded Bolts
NSTS 1700.7B January 1989	Safety Policy and Requirements For Payloads Using the Space Transportation System
NSTS 1700.7B ISS Addendum, December 1995	Safety Policy and Requirements For Payloads Using the International Space Station
NSTS 14046 Rev. D, July 1997	Payload Verification Requirements Space Shuttle Program
NASA-STD-5001 June 21, 1996	Structural Design and Test Factors of Safety for Space Flight Hardware

2.3 Reference documents.

The documents in this paragraph are provided only as reference material for background information and are not imposed as requirements.

FIR-RPT-0141 Preliminary	FIR Mass Properties Control Report
FCF-PLN-0029 Preliminary	Fastener Control Plan Fluids and Combustion Facility
FF-S-86 Rev. E, 1/16/91	Federal Specification Screw, Cap, Socket Head
MSFC-STD-486 Revision B, November 1992	Standard, Threaded Fasteners, Torque Limits For
MSFC-STD-561A February, 1995	Threaded Fasteners, Securing of Flight Hardware used on Shuttle Payloads and Experiments
MIL-S-8879C 8/12/97	Screw Threads, Controlled Radius Root With Increase Minor Diameter, General Specification For
AMS 5731 Rev. J, 8/15/90	Aerospace Material Specification Steel, Corrosion and Heat Resistant, Bars, Wire, Forgings, Tubing, and Rings 15 Cr - 25.5 Ni - 1.2 Mo - 2.1 Ti - 0.006 B - 0.30 V Consumable Electrode Melted, 1800 F (982 C) Solution Heat Treated
MSFC-HDBK-527 JSC 09604 September 30, 1988	Materials Selection List for Space Hardware Systems
MIL-HDBK-5H 12/1/1998	Metallic Materials and Elements for Aerospace Vehicle Structures
Prepared By: Vernon R. Beatty June 14, 2000	Structural Analysis Report for the Electrical Power Control Unit Hamilton Sundstran/A United Technologies Company
Version 70.7.0 October 8, 1999	MSC NASTRAN MSC Software Corporation
Release 9.0 December, 1999	MSC PATRAN 3 MSC Software Corporation

3.0 STRUCTURAL DESIGN CRITERIA

3.1 Weight Requirements

The FIR is limited to 804.2 kg (1773 lbs.) for launch and landing in the MPLM and for ground and on-orbit operations as specified in Paragraph 3.1.1.4A of SSP 57000.

The FIR will not be fully integrated at either launch or landing when transported in the MPLM. Electronic instruments and mechanical equipment that are designated as being either delicate or functionally precise, (i.e., cameras, lasers, etc.) will be packed in foam and placed in storage to provide additional protection from the launch and landing load environments. The FIR will be at its largest mass when fully integrated either on the ground or on orbit in the ISS.

The FIR mass breakdowns and estimates for launch and landing in the MPLM and when fully integrated either on the ground or on orbit are shown in Table I as referenced from FIR-RPT-0141.

Table I. FIR Mass Properties Summary

FIR Mass Summary		Fully Integrated Rack on the Ground and On Orbit		Launch and Landing in the MPLM	
Assembly		Base Estimate (Kg)	Base Estimate (lbm)	Base Estimate (Kg)	Base Estimate (lbm)
FIR ELEMENT	Optics Bench Assembly (includes optics bench, Support Plates, and Seals)	141.87	312.12	141.87	312.12
	Cameras & IAMs (includes high frame rate camera)	12.58	27.68		
	Translation Stage	5.17	11.36		
	Lasers (Nd: Yag & Laser Diodes)	10.33	22.77		
	Illumination (White light)	4.49	9.90		
	Lens Assembly (2 macro lens, color lens, hi-mag lens)	4.55	10.01		
	SCANNING MIRROR	4.54	9.98		
	COLLIMATOR	1.08	2.38		
	Light sheet and calibration equipment	2.41	5.31		
	MOBILE FANS (Fan Post)?	0.68	1.49		
	PI-FSAP	12.32	27.10	12.32	27.10
	FSAP	15.83	34.83	15.83	34.83
	IPSUs (QTY. 2)	15.64	34.48	15.64	34.48
PI	PI Experiment Package	65.00	143.00		
COMMON H/W	DCMs (QTY. 6)	13.02	28.64		
	RACK DOORS	20.00	44.00	20.00	44.00
	Pin Assemblies	5.95	13.09	5.95	13.09

	Misc Structures (includes center post and IOP mounts); Rack Attachment HW	5.18	11.39	5.18	11.39
	I/O Processor	29.14	64.11	29.14	64.11
	Slides (includes Rotational & Brake Assemblies) (UPDATE w/CIR)	63.88	140.53	63.88	140.53
	Removable Latch for Diagnostics Mount	2.57	5.67		
	ECS - Water Distribution & Control Assy	32.54	71.74	32.54	71.74
	ECS-Accumulator Assembly (Removed on orbit)			3.40	7.50
	ECS - Air Thermal Control Assembly	60.18	132.67	60.18	132.67
	Gas Interface Assy	16.23	35.72	16.23	35.72
	Fire Detection & Suppression Assy	2.47	5.43	2.47	5.43
	Experiment Assembly - FIR Service Umbilical Set	7.11	15.67	7.11	15.67
GFE	ARIS - Launch Condition*	61.06	134.33	61.06	134.33
	ARIS - Additional On-Orbit Mass[1]	14.45	31.79		
	Electrical Power Subsystem	58.04	127.95	58.04	127.95
	SAMS Subsystem	1.23	2.71	1.23	2.71
	Rack - Rack Assembly (includes RUP?)	111.90	246.70	111.90	246.70
	Rack-Rack to Station I/F umbilical set (ARIS)	10.66	23.44		
	GROSS TOTALS	**815.50**	**1797.87**	**663.97**	**1463.80**
	Integrated Rack Limit	**804.20**	**1773.0**	**804.20**	**1773.0**

Note:
1. ARIS control mass modified to reflect S684-10158 PIDS, paragraph 3.2.2.8. ARIS has a total weight of no greater than 191lbs. and launch weight of no greater than 138 lbs.
2. The masses in Table I will be changing and updated in FIR-RPT-0141 as the FIR Rack design evolves and becomes more defined. Masses current to 9/14/00.

3.2 Natural Frequency Requirements

FIR hardware mounted directly to the ISPR shall have a minimum natural frequency greater than or equal to 35 Hz when rigidly mounted at the component to rack interface. (Paragraph 3.1.1.4D of 57000).

3.3 Thermal Environment

The thermal environment in which FIR is exposed to in the MPLM and on orbit in the ISS is shown in Table II.

Table II. FIR Thermal Environment

Thermal Environment	Minimum Temperature °C (°F)	Maximum Temperature °C (°F)
MPLM Launch /Ascent (Table 4.6.2-1, SSP 57020)	4.4 (40.0)	48.9 (120)
MPLM Descent/Landing (Table 4.6.2-1, SSP 57020)	4.4 (40.0)	48.9 (120)
FIR Rack on Orbit (Non Operating) (Paragraph 3.9.1.2, SSP 57000])	10 (50)	46 (115)
FIR Rack on Orbit[1] (Operating) (TBD Thermal Analysis)	16.1 (61) Based on the Minimum Water Temperature	TBD[1] PI Specific Configuration @ Operation
FIR Rack on Orbit[1] (Nominal Operation) (TBD Thermal Analysis)	16.1 (61) Based on the Minimum Water Temperature	40.6 (105) Warmest Air Temperature

Note:
1. To be determined by the FIR Rack Thermal Analysis. These values will vary with the optics plate configuration and the types of experiments being performed on the optics plate.

3.4 Payload Loading Conditions

3.4.1 Low Frequency Transient Load Factors

The launch and landing low frequency transient load factors in the MPLM and the on-orbit load factors for the FIR Components mounted to an ISPR are summarized in Table III as Referenced from SSP 57000.

Table III. Payload ISPR Mounted Equipment Load Factors

(Equipment Frequency 35 Hz)

LOADING EVENT	X (G's)	Y (G's)	Z (G's)
LIFTOFF	± 7.7	± 11.6	± 9.9
LANDING	± 5.4	± 7.7	± 8.8
ON-ORBIT ISS	0.2 G's in any Direction (Paragraph 3.1.1.3B of SSP 57000)		

Note:
1. The load factors above act in the rack coordinate system defined in SSP 41017, Part 2, Paragraph 3.1.3 and are applied concurrently in all possible combinations for each event. By observation, the Liftoff Loads are more critical.
2. As Referenced in SSP 57000, the load factors for Liftoff and Landing will be superceded by load factors obtained through ISS performed Coupled Loads Analysis as described in SSP 52005.

3.4.2 Emergency Landing Load Factors

The emergency landing load factors are enveloped by the Low Frequency Load Factors shown in Section 3.4.1 above as Referenced in Paragraph 4.1.4 of SSP 52005.

3.4.3 Random Vibration Criteria

For design and qualifications purposes, the FIR Components mounted to ISPR posts shall maintain positive margins of safety for the MPLM ascent random vibration environment defined in Table IVand Table V as referenced from Table 3.1.1.3-2 and Table 3.3.3.3-3 of SSP 57000;

Table IV. Random Vibration Criteria for ISPR Post-Mounted Equipment Weighing 100 Pounds or Less in the MPLM

Frequency Hz	Level
20	0.005 g^2/Hz
20-70	+ 5.0 dB/Oct
70-200	0.040 g^2/Hz
200-2000	-3.9 dB/Oct
2000	0.002 g^2/Hz
Composite	4.4 Grms
Note: Criteria is the same for all directions (X, Y, Z)	

Table V. Random Vibration Criteria for ISPR Post-Mounted Equipment Weighing More Than 100 Pounds in the MPLM

Frequency Hz	Level
20	0.002 g^2/Hz
20-70	+ 4.8 dB/Oct
70-150	0.015 g^2/Hz
150-2000	-3.7 dB/Oct
2000	0.0006 g^2/Hz
Composite	2.4 Grms
Note: Criteria is the same for all directions (X, Y, Z)	

3.4.4 Acoustic Load Factors

Not Applicable. Enveloped by the load factor combinations of the low frequency transient load factors and the random vibration load factors.

3.4.5 Pressure Environment

The primary structure of the FIR Optics Bench Assembly with its supporting members and hardware to the ISPR posts do not consist of any hermetically sealed volumes classified as either a pressure vessel or a sealed container. However, there are enclosed volumes, not sealed volumes, internal to the Optics Bench itself. A Depressurization/Repressurization Analysis shall be performed on the FIR Optics Bench to verify sufficient venting in the event of depress or repress of the MPLM and ISS thus preventing deformations of the FIR Optics Bench.

From Paragraph 3.1.1.2B of SSP 57000, “The integrated racks shall maintain positive margins of safety in the MPLM at depress rates of 890 Pa/second (7.75 psi/minute) and repress rates of 800 Pa/second (6.96 psi/minute).”

Note: The depress and repress rates of the MPLM envelope the maximum depress (878 Pa/s, 7.64 psi/min) and maximum repress (230 Pa/s, 2 psi/min) of the ISS due to fire suppression, controlled module depressurization, and controlled module repressurization from Paragraph 3.1.7.2.1 of SSP 41002.

3.4.6 Crew Induced Loads

The FIR Rack shall have positive margins of safety when exposed to the crew induced loads defined in Table 3.1.1.3-1 of SSP 57000. The loads are summarized in Table VI.

Table VI. Crew Induced Loads

Crew System or Structure	Type of Load	Load	Direction
Levers, Handles, Operating Wheels, Controls	Push or Pull concentrated on most extreme edge	222.6 N (50 lbf) Limit	Any Direction
Small Knobs	Twist (torsion)	14.9 N-m (11 ft-lbf) Limit	Either Direction
Exposed Utility Lines (Gas, Fluid, and Vacuum)	Push or Pull	222.6 N (50 lbf) Limit	Any Direction
Cabinets and any Normally Exposed Equipment “Crew Push-Off Loads”	Load distributed over a 4 inch x 4 inch area	556.4 N (125 lbf) Limit	Any Direction

3.5 Safety Factors for ISPR Attached Structures

Table VII summarized from Table 5.1.2-1 of SSP52005 and NASA-STD-5001 lists the minimum Factors of Safety (FOS) which will be used to analyze the FIR structural hardware;

Table VII. Factors of Safety

	FOS Yield	FOS Ultimate	FOS Proof	FOS Joint Separation
Metallic Structures				
Untested Shuttle (analysis only)	1.25	2.0		
Untested on Orbit (analysis only	1.25	2.0		
Tested Shuttle (analysis and test)	1.0	1.4	1.2	
Tested on Orbit (analysis and test)	1.1	1.5	1.2	
Minimum Factor of Safety for all Mission Phases except Emergency Landing. (NSTS 1700.7B, Paragraph 208.1 of Reference [5])		1.4		
Emergency Landing		1.0		
Fasteners – Pressure/Hazardous Fluid Applications				1.4
Fasteners – Structural Applications				1.2
Fail Safe Analyses		1.0		1.0

3.6 Fasteners

Margins of Safety will be determined for all Safety Critical Fasteners based on the requirements and guidelines presented in Appendix F of SSP 52005, NSTS 08307, and FF-S-86E. All fasteners will be torqued in accordance with MSFC-STD-486 and SSP 57007.

Attempts will be made to purchase all safety critical structural fasteners as Military Standard Specification (MS) or National Aerospace Specification (NAS). All safety critical fasteners will be made of heat and corrosion resistance A286 stainless steel material. Likewise, the inserts to which these fasteners interface will also be made of A286 stainless steel material.

All threaded fastener interfaces will be provided with means of a positive locking device as Referenced in MSFC-STD-561A. Positive locking features for Safety Critical Fasteners that are NOT Fracture Critical, either contained or redundant/fail-safe, will use locking compounds (i.e., Loctite), locking inserts, or self locking threaded devices (i.e., locking patch, pellet, or strip). Safety Critical Fasteners classified as Fracture Critical will use positive locking devices such as safety wire, safety cable, cotter pins and locking compounds. Fasteners requiring removal and replacement of specific hardware, as well as access within specific hardware for maintenance purposes during the life of FIR, will be either captive or tethered and will not be safety wired.

Material certification reports, both chemical and physical properties, tensile tests, and chemical analyses will be obtained on each lot of safety critical fasteners as Referenced in FCF-PLN-0029, the Fastener Control Plan.

The design intent of the FIR Rack is to not have any Fracture Critical Fasteners.

3.6.1 ISPR Fastener Interface Requirements

This Section is referenced from SSP 57007. The following sections will summarize the fastener requirements for interfacing into the ISPR.

3.6.2 ISPR Fastener Interfaces

There are two types of hole patterns which are provided for the payload integrator’s use; the .250 diameter fastener hole pattern in the side/center post, and the .190 diameter fastener hole pattern on the front of the rack next to the cargo track and on the front of the center post.

3.6.3 Side Post Hole Size

The .250 diameter hole pattern is provided for payload structural attachments. The .257–.261 diameter hole in the side/center post are a **“CLASS II or CLEARANCE FIT”**. Hole diameters should be chosen as liberally as strength and functioning considerations permit. Bolted connections have been divided into three “classes or fits”. The classes or fits are defined in general by the design requirements. These classes or fits include most bolted connections for both structure and equipment, and nearly every design can be made to fall definitely within one of these classifications:

“CLASS III or LOOSE FIT” – Class III or loose fit holes are for tension attachments with only incidental shear loads and for general bracket attachment, etc. where vibration or hammering are not present.

“CLASS II or CLEARANCE FIT” – Class II or clearance holes are for general shear load attachments where multiple bolts are used and usually non–reversing loads.

“CLASS I or CLOSE FIT” – Class I or close fit holes are for shear load attachments involving only one tight bolt which is highly stressed or subjected to frequent reversing loads. Multi–bolt patterns must be drilled on assembly.

3.6.4 Closeout Panel Hole Size

The .190 diameter fastener hole pattern is provided for close–out panels. The .190 diameter fastener hole is .281 +/– .005 per EIA–310–C, Racks, Panels and Associated Equipment. This interface is considered non–structural for a .190 diameter fastener. A class III slot in the Rack's X direction is recommended for non–structural close–out panels.

3.6.5 Fastener Selection

The use of high strength threaded fasteners is recommended for structural and equipment installation. A minimum of 160 Ksi Ftu strength fasteners are recommended for attaching into the ISPR provided floating locking nut elements. ISPR provided floating locking nut elements in the side post are .2500 – 28 UNJF – 3B (per MIL–S–8879), made of A–286 (usually AMS 5731) and dry film lubed or silver-plated. ISPR provided floating locking nut elements for close–out panels are .190–32 UNJF – 3B (per MIL–S–8879), made of A–286 (usually AMS 5731) and are silver plated. Table VIII lists the fasteners that have been widely used on the rack structure and in Boeing internal rack integration.

Table VIII. Recommended ISPR Interface Hardware

HEX HEAD BOLT	SOCKET HEAD CAP SCREW	100 DEG FLUSH HEAD BOLT	WASHER
NAS6303 – NAS6320	NAS1351 (Fine Thread)	NAS1580	NAS1587 (C'Sink & Flat)
	NAS1352 (Coarse Thread)	NAS1581 (Reduced Head)	NAS620 (Reduced Dia.)

3.6.6 Fastener Torque Guidelines

Fastener torque values should be placed on the applicable assembly or installation drawing for special or critical wrench torques. All of the rack fasteners (with exception of any Eddie–bolt) were installed and torqued to the requirements found in MSFC–STD–486 shown in Table IX below. Torque values shown in Table IX are to be applied above the running torque of the locking device, using Braycote 601 or 601 EF grease (cage code 2R128) sparingly as an antiseize agent, not as a lubricant, to bolt threads.

Table IX. Fastener Torques

BOLT TYPE, KSI MIN	TENSILE 160 Ft_u	SHEAR 95 Fs_u
FASTENER SIZE	**TORQUE, INCH - POUNDS**	
0.1900 – 32	25 – 30	15 – 18
0.2500 – 28	65 – 75	38 – 45

4.0 MATERIAL PROPERTIES

The material properties for the safety critical structures analyzed in this report are summarized in Table X. The minimum material properties were obtained from MIL-HDBK-5 and the fastener procurement Specification FF-S-86. The materials all have an “A” rating for stress corrosion cracking per MSFC-HDBK-527 and JSC 09604.

Table X. Fluids Integrated Rack Material Properties

				E	Fty	Fcy	Ftu	Fcu	Fsu	Fbu	Density	SCS No
Material	Form	Condition	Specs	(ksi)	(ksi)	(ksi)	(ksi)	(ksi)	(ksi)	(ksi)	(lbs/in^3)	SEE Figure 7 and Figure 8
6061-T651 Aluminum	Plate	0.25-2.0-A minimum	MIL HDBK 5H	9.9	35	35	42	42	27	67	0.098	1, 9, 13
7075-T7351 Aluminum	Plate	0.25-0.5-S minimum	MIL HDBK 5H	10.3	57	56	68	68	38	102	0.101	2 – 6, 15 – 19
300 Stainless Steel	Sheet	Full Hard-A minimum	MIL HDBK 5H	26.0	125	83	174	174	95	346	0.286	7,8, 11,12
300 Stainless Steel	Sheet or Strip	Annealed – S minimum	MIL HDBK 5H	29.0	26	23	73	73	50	162	0.286	10,14
A-286 Stainless Steel	Fastener	Rolled Threads	FF-S-86-E	30.0	120	120	160	160	97	195	0.290	101 – 119

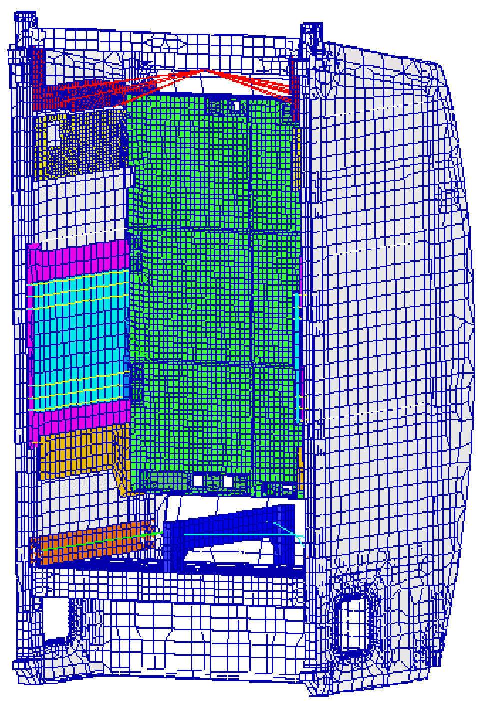
5.0 FINITE ELEMENT MODEL

Figure 1 shows the FIR finite element model with some of the common FCF systems (i.e., EPCU, IOP, and ATCU) integrated within a Boeing provided finite element model of the ARIS/ISPR. This model depicts the FIR launch configuration within the MPLM. This integrated finite element model was provided to Huntsville/Boeing for their rack level analyses.

The FIR finite element model is interfaced to the ISPR posts using spring elements to depict the axial and shear stiffness of the bolted connection.

As noted, the common doors are not included within this model. The doors are planned to be included once the design is complete. The doors will provide additional stiffness to the rack since they are being designed as structural members mounted to the ¼”-28 fasteners of the front rack posts.

Items of significant mass not included within this model include the doors mentioned above, the ECS (Water Distribution and Control Assembly (32.54 Kg.)), and the Gas Interface Assembly (16.23 Kg.). These gas lines, water lines, associated valves, and fittings are primarily mounted to and run along the rear posts, distributed throughout the rear of the rack from top to bottom.



Note: Common Door is not shown. Doors are currently being designed.

Figure 1. FIR Integrated ISPR/ARIS Finite Element Model

Figure 2 shows a front view and rear view of the FIR finite element model. The finite element model is constructed as follows;

- 16,813 Nodes
- 100,878 Degrees of Freedom
- 16,497 Plate and Bar Elements. The majority of the elements are plate elements made up of CQUAD4 and CTRIA3. The Bar Elements are CBAR.
- 726 Multipoint Constraints (MPC)
- 7 Lumped Masses (CONM2). Common FCF hardware such as the ATCU, EPCU, and IOP were modeled as lumped masses. Subassemblies such as the IPSU's, FSAP, and PI-FSAP mounted to the rear of the optics bench were also modeled as lumped masses.

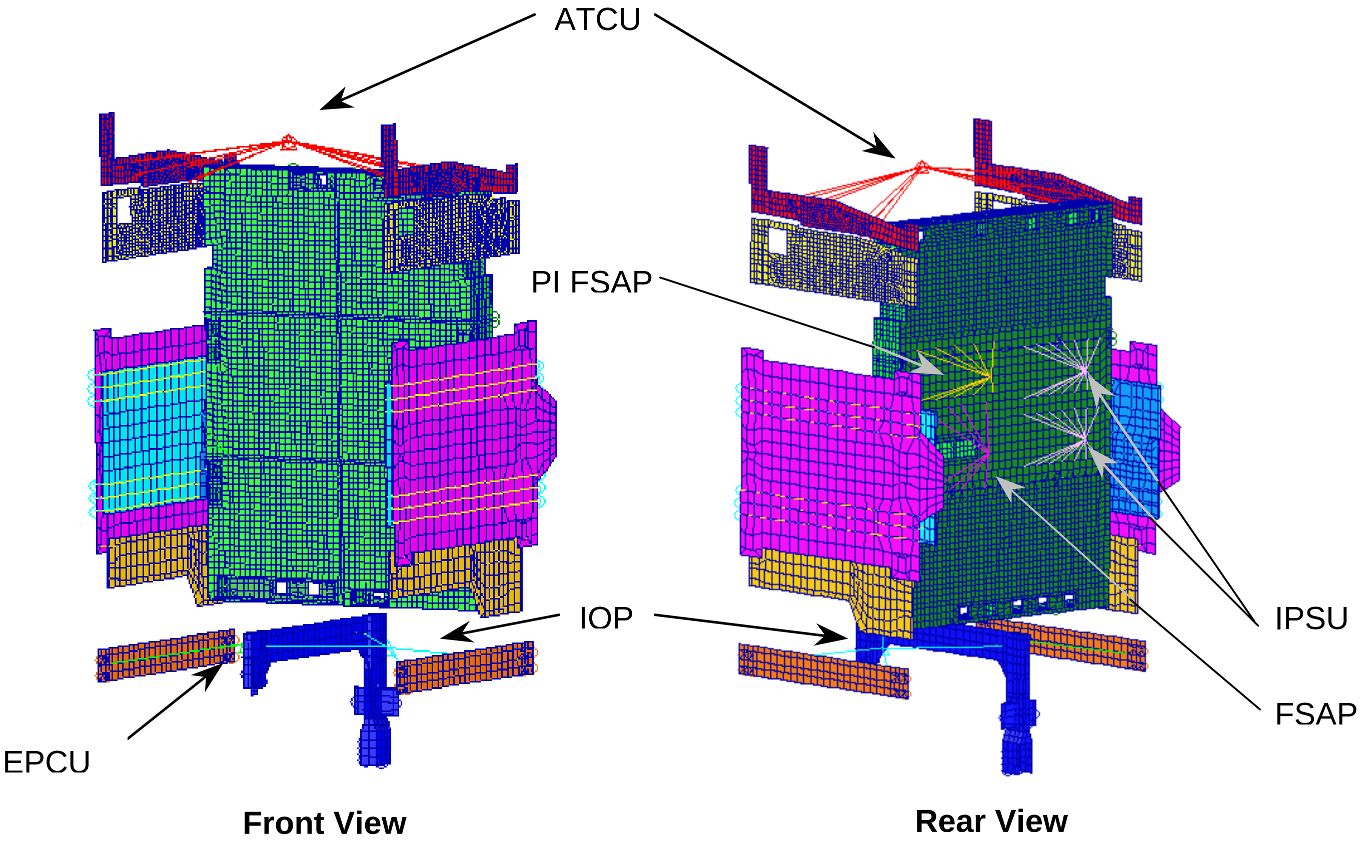


Figure 2. FIR Finite Element Model

6.0 FIR FEA MODEL MASS PROPERTIES

A mass comparison was made between the FIR FEA model and the Fir Mass Properties Report, FIR-RPT-0141. The itemized listing of the structural components shown in Table XI identifies the structures that were modeled with either, more, less, or the same mass as those in the Mass Properties Report. Flagging these mass discrepancies now will aid in the tracking and further development of the FEA model as the designs become more mature.

Items that need to be included in the FIR ISPR model are the Common Doors, Gas Interface System, and the ECS, Water Distribution and Control System. These Items will add approximately 70.3 Kg (155 Lbs.) of Mass to the ISPR structure.

In general, the FIR FEA model is slightly more massive (611.4 Kg) than the estimates (602.32 Kg) developed in the FIR Mass properties Report. The mass properties of the FIR FEA model shown in Table XII are output form the NASTRAN grid point weight generator (units are in lbs. and inches).

Table XI. Mass Comparison of the FIR FEA Model to the Mass Properties Report

Description of Component	SCS No.	FEA Model Weights		FIR-RPT-0141
		Component Weight Kg (Lbs.)	Assembly Weights Kg (Lbs.)	Weight From Mass Properties Report Kg (Lbs.)
FIR Optics Bench and Support Structure				
Optics Bench Assembly (Density increased to account for 50 Lbs. of miscellaneous weights, i.e., Fasteners, Electrical Cabling, and Water Lines)			121.7 (268.3)	
Optics Bench	1	93.3 (205.6)		93.0 (205.0)
Rear Plate of Optics Bench Assembly	2	28.4 (62.7)		34.1 (75.2)
Upper Support Brackets (2) (Includes the weight of the Pin Assemblies)	5,6	15.6 (34.5)	15.6 (34.5)	17.6 (38.8)
Lower Support Brackets (2)	17,18	7.5 (16.5)	7.5 (16.5)	10.6 (23.4)
Slide Assemblies (2) (Includes the weight of the Rotational and Translational Brake Assemblies)			85.6 (188.8)	85.6 (188.7)
Inner Slide Stiffening Plates (2)	9,13	7.5 (16.5)		
Inner Slide Support Plates (2)	8,12	19.5 (42.9)		
Slides Mechanisms (2)	10,14	30.4 (67.1)		
Outer Slide Support Plates (2)	7,11	28.3 (62.3)		
FIR Subassemblies				

IPSU (2)		18.1 (40.0)	18.1 (40.0)	15.64 (34.5)
FSAP		24.5 (54.0)	24.5 (54.0)	15.83 (34.9)
PI – FSAP		14.5 (32.0)	14.5 (32.0)	12.32 (27.2)
Common FCF Hardware				
ATCU Assembly			63.77 (140.6)	
ATCU Support Brackets (2)	3,4	6.6 (14.6)		5.18 (11.4)
ATCU Unit		57.2 (126.0)		55.0 (121.3)
EPCU/IOP Assembly			82.0 (180.7)	
EPCU/IOP Rack Side Supports (2)	17,18	4.5 (9.9)		6.3 (13.9)
EPCU/IOP Center Support	19	3.5 (7.8)		4.2 (7.7)
EPCU		50.3 (111.0)		50.3 (110.9)
IOP		23.6 (52.0)		23.8 (52.5)
Door Assembly (Not in FEA Model - Currently estimated at 44.0 Lbs.)		TBD	TBD	TBD
Gas Interface Assembly (Not in FEA Model - Currently Estimated at 35.72 Lbs. - Distributed on one side at rear of rack)		TBD	TBD	TBD
ECS - Water Distribution and Control Assembly (Not in FEA Model - Currently Estimated at 75.25 Lbs - Distributed on at rear posts)		TBD	TBD	TBD
Government Furnished Equipment				
ISPR with ARIS (Model Provided by Boeing)		178.1 (392.6)	178.1 (392.6)	172.9 (381.2)
Total Modeled Weights		611.4 (1348)		602.32 (1327.88)
Total Estimated Weights from the Mass Properties Report FIR-RPT-0141				
ARIS/ISPR Allowables	804.20 (1773.0)			

Table XII. FIR FEA Model Mass Properties

O U T P U T F R O M G R I D P O I N T W E I G H T G E N E R A T O R

REFERENCE POINT = 0

M O

*	1.347623E+03	0.000000E+00	0.000000E+00	0.000000E+00	5.046011E+04	1.074336E+04	*
*	0.000000E+00	1.347623E+03	-3.118894E-25	-5.046011E+04	0.000000E+00	2.631695E+04	*
*	0.000000E+00	-3.118894E-25	1.347623E+03	-1.074336E+04	-2.631695E+04	0.000000E+00	*
*	0.000000E+00	-5.046011E+04	-1.074336E+04	2.783375E+06	2.047265E+05	-9.902514E+05	*
*	5.046011E+04	0.000000E+00	-2.631695E+04	2.047265E+05	3.363144E+06	4.258602E+05	*
*	1.074336E+04	2.631695E+04	0.000000E+00	-9.902514E+05	4.258602E+05	9.692426E+05	*

S

*	1.000000E+00	0.000000E+00	0.000000E+00	*
*	0.000000E+00	1.000000E+00	0.000000E+00	*
*	0.000000E+00	0.000000E+00	1.000000E+00	*

DIRECTION

MASS AXIS SYSTEM (S)	MASS	X-C.G.	Y-C.G.	Z-C.G.
X	1.347623E+03	0.000000E+00	-7.972082E+00	3.744379E+01
Y	1.347623E+03	1.952843E+01	0.000000E+00	3.744379E+01
Z	1.347623E+03	1.952843E+0	-7.972082E+00	0.000000E+00

I(S)

*	8.083108E+05	5.074384E+03	4.844960E+03	*
*	5.074384E+03	9.597972E+05	-2.358804E+04	*
*	4.844960E+03	-2.358804E+04	3.696670E+05	*

I(Q)

*	3.686767E+05		*
*		9.609202E+05	*

*   8.081781E+05 *

Q

* 1.055196E-02 3.446694E-02 9.993501E-01 *

* -3.977954E-02 -9.986002E-01 3.486110E-02 *

* 9.991528E-01 -4.012154E-02 -9.166108E-03 *

7.0 MODAL ANALYSIS

A Normal Modes analysis was performed on the FIR assembly using Solution 103 of MSC NASTRAN. The Lanczos Method of Eigenvalue extraction was used. Boundary conditions were established at the FIR to ISPR interface nodes. The three translational degrees of freedom were constrained at these interface nodes.

Table XIII shows the primary structural modes of the FIR assembly based on its largest modal mass participation in the X, Y, and Z directions. The mode shapes representing each of these structural modes are shown in Figure 3 through Figure 5.

Table XIII. The Primary Structural Modes of the FIR Assembly

Modal Frequency (Hz.)	Description	**Mass Participation** (Lbs.)		
		X Direction	Y Direction	Z Direction
88.3 (Figure 3)	Side sway of Optics Bench/ Bending of Slides X Direction	122.3	0.0	0.0
92.7 (Figure 4)	Bending of Optics Bench/ In and Out Motion of Slides Y Direction	1.7	250.3	0.0
384.4 (Figure 5)	Up and Down Motion of Optics Bench Z Direction	0.2	0.2	115.8

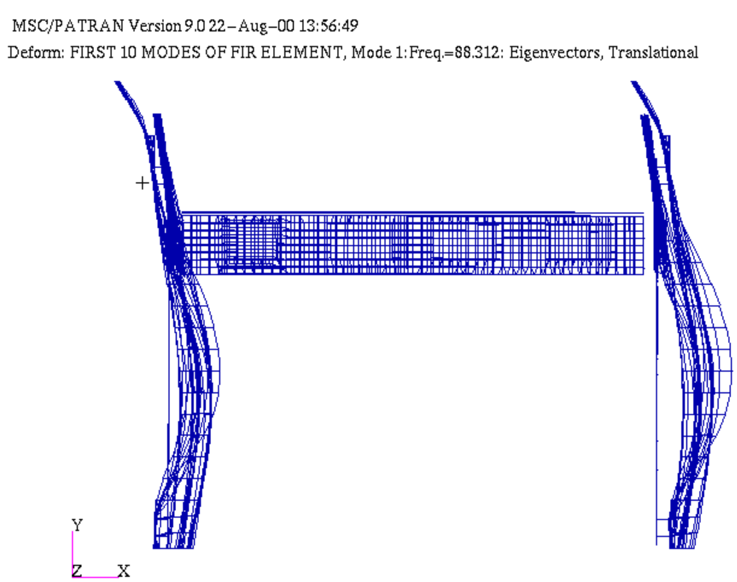


Figure 3. FIR Structural Mode - X Direction 88.3 Hz

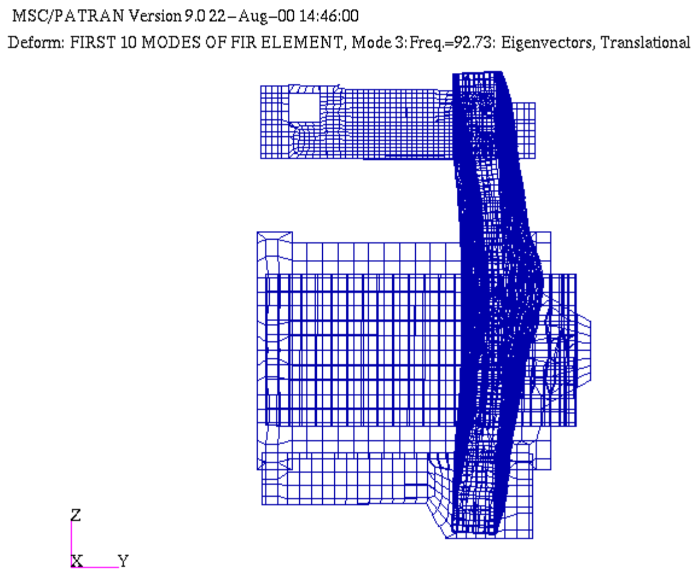


Figure 4. FIR Structural Mode - Y Direction 92.7 Hz

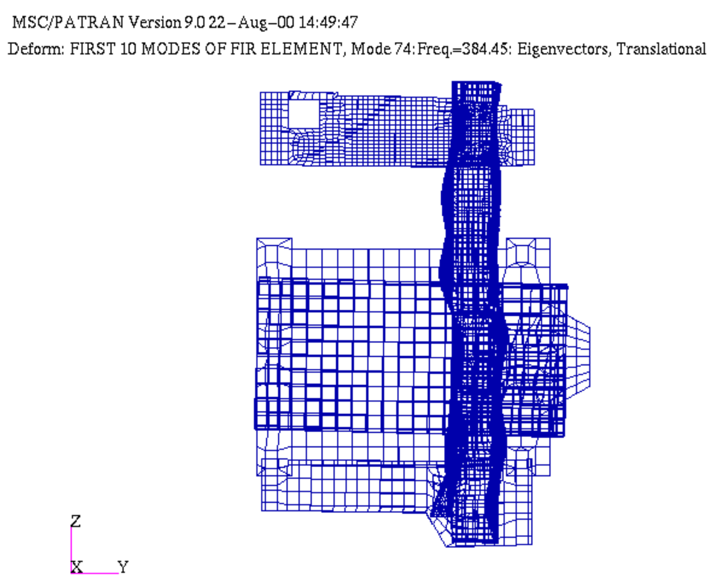


Figure 5. FIR Structural Mode - Z Direction 384.4 Hz

The modal analysis shows its fundamental structural mode, 88.3 Hz in the X direction, is well above the rack requirement of 35 Hz presented in paragraph 3.1.1.4 of SSP 57000 for a component rigidly attached at the component to rack interface.

A rigid body analysis was used to check the FIR model for any hidden constraints. The translational constraints were released at the FIR to ISPR interface nodes. The first six modes were identified as rigid body modes between 0.000039 Hz and 0.000191 Hz. The seventh mode at 18.9 Hz represented a slide-bending mode in the X direction.

8.0 DESIGN LOAD FACTORS

The RVLF's will be based on the structural modes presented in the modal analysis of Section 7.0 and the random vibration criteria for ISPR post-mounted equipment weighing more than 100 pounds in the MPLM from Table V of Section 3.4.3.

The Mile's Equation will be used to determine the Random Vibration Load Factors (RVLF) for each translational direction shown in Table XIV. Since no test data is available, the resonant amplification factor, Q, will be set to 10.

Table XIV. FIR Random Vibration Load Factors

Frequency Hz	**Direction**	**Slope dB/oct**	**PSDn g^2/Hz**	**Q**	**RVLF (g)** **Mile's Equation=3(p/2*Q*f_n*PSD_n)^1/2**
88.3	X	NA	0.0150	10.	13.8
92.7	Y	NA	0.0150	10.	14.1
384.4	Z	-3.7	0.0047	10.	16.0

The RVLF's of Table XIV will be combined with the low frequency transient liftoff design load factors in Table III by root summing the squares. The load combination criteria referenced from Table 4.1.2-1 of SSP 52005 are presented in Table XV below for the FIR structure.

Table XV. Load Combinations for the FIR Structure

Load Set	**X Axis**	**Y Axis**	**Z Axis**
Lift -Off			
1	$1.5 \pm [(7.7-1.5)^2 + 13.8^2]^{1/2}$ $= (1.5 \pm 15.2)$	$\pm$ 11.6	$\pm$ 9.9
2	$\pm$ 7.7	$(11.6^2 + 14.1^2)^{1/2}$ $= (\pm 18.2)$	$\pm$ 9.9
3	$\pm$ 7.7	$\pm$ 11.6	$(9.9^2 + 16.0^2)^{1/2}$ $= (\pm 18.8)$
Landing			
4	$\pm$ 5.4	$\pm$ 7.7	$\pm$ 8.8

The load combination criteria shown in Table XV will produce 24 Lift-Off Load Combinations and 8 Landing Load Combinations. As shown in Table XVI, the 24 Lift off Load Cases will be used in subsequent stress analyses since they envelope the Landing Load Cases.

Table XVI. Load Factors for the FIR Structure

Load Set	X Axis	Y Axis	Z Axis
Lift -Off			
1	-13.7	11.6	9.9
2	-13.7	11.6	-9.9
3	-13.7	-11.6	9.9
4	-13.7	-11.6	-9.9
5	16.7	11.6	9.9
6	16.7	11.6	-9.9
7	16.7	-11.6	9.9
8	16.7	-11.6	-9.9
9	7.7	18.2	9.9
10	7.7	18.2	-9.9
11	7.7	-18.2	9.9
12	7.7	-18.2	-9.9
13	-7.7	18.2	9.9
14	-7.7	18.2	-9.9
15	-7.7	-18.2	9.9
16	-7.7	-18.2	-9.9
17	7.7	11.6	18.8
18	7.7	11.6	-18.8
19	7.7	-11.6	18.8
20	7.7	-11.6	-18.8
21	-7.7	11.6	18.8
22	-7.7	11.6	-18.8
23	-7.7	-11.6	18.8
24	-7.7	-11.6	-18.8
Landing			
25	5.4	8.8	7.7
26	5.4	8.8	-7.7
27	5.4	-8.8	7.7
28	5.4	-8.8	-7.7
29	-5.4	8.8	7.7
30	-5.4	8.8	-7.7
31	-5.4	-8.8	7.7
32	-5.4	-8.8	-7.7

9.0 STRESS ANALYSIS

9.1 Load Path Diagram

Figure 6 shows the load path of the FIR Structural Elements and the FCF Common Structural Elements (ATCU, Doors, EPCU, and IOP) to the ARIS equipped ISPR.

As shown, there are basically four separate structural systems that are mounted to the ISPR posts. The FIR Optics Bench including hardware mounted to its rear plate (FSAP, PI-PSAP, IPSU's) is supported from the top and bottom support plates and common FCF slide assemblies. The ATCU is supported from common FCF side supports. Where as, the EPCU and IOP are supported in the lower section of the rack by its common FCF support plates and common FCF center support.

The FCF Common Door assembly will be supported from the existing support structure in addition to the ISPR structure. The doors will utilize the ATCU side supports, the FCF slide assemblies, the ISPR posts, and a Lower Z Bar attached to the ISPR structure.

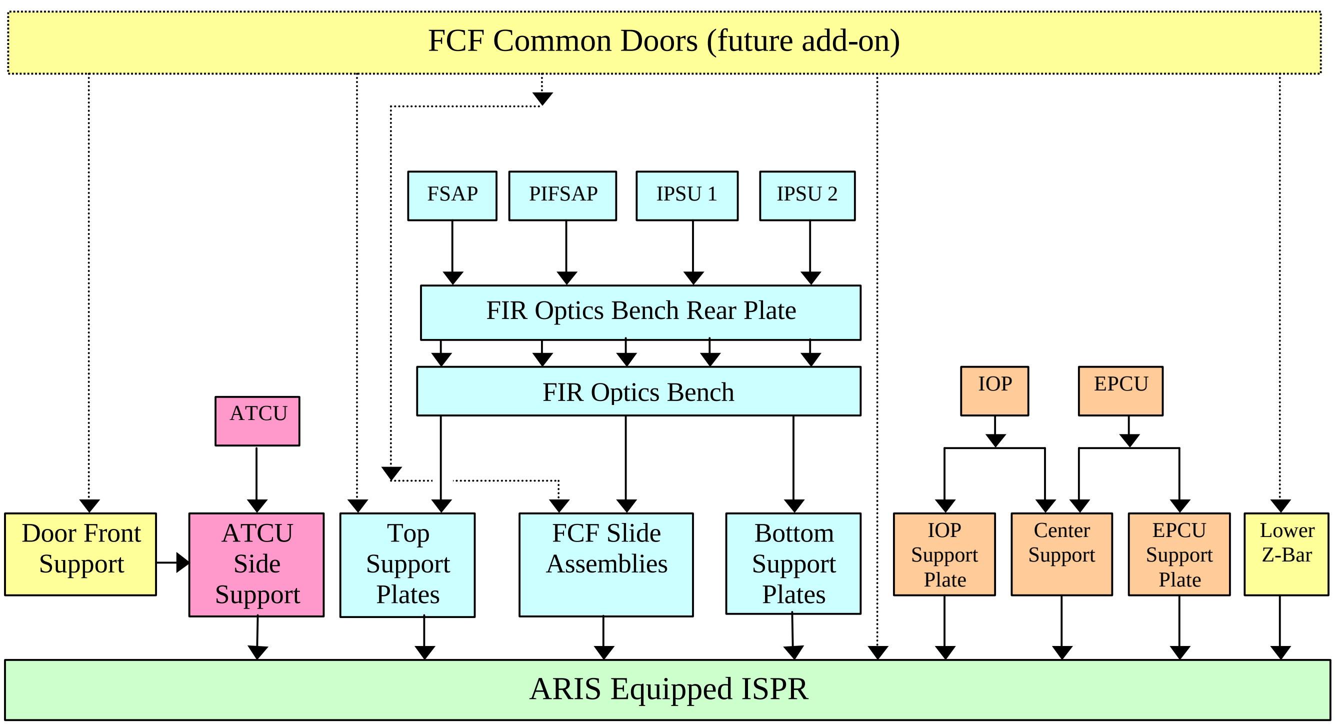


Figure 6. Load Path Diagram

9.2 Structural Components

A linear static analysis was performed on the finite element model using MSC/NASTRAN, Solution 101. The 24 lift-off load cases shown in Table XVI of Section 8.0 were applied to the model.

The element results were post processed using MSC/PATRAN and sorted across all 24 loading conditions. Centroidal element stresses were obtained based on the Maximum and Minimum Principal Stresses and the Maximum Shear Stresses as shown in Table XVII.

A spreadsheet program, MS Excel, was used to determine the margins of safety for each of the safety critical structural components shown in

Figure 7 based on the maximum and minimum principal and shear stresses as outlined in Appendix C.2. The Margins of Safety for the Safety Critical Components are summarized in Table XVIII.

All component stress margins of safety were determined to be positive. The lowest safety margin was 0.15, which occurred in the upper right support plate to the optics bench. The support plate experienced high tensile stress in the Z1 plane when subjected to Load Case 8 as defined in Table XVII. This region also demonstrated significant fastener loads, discussed in the next section.

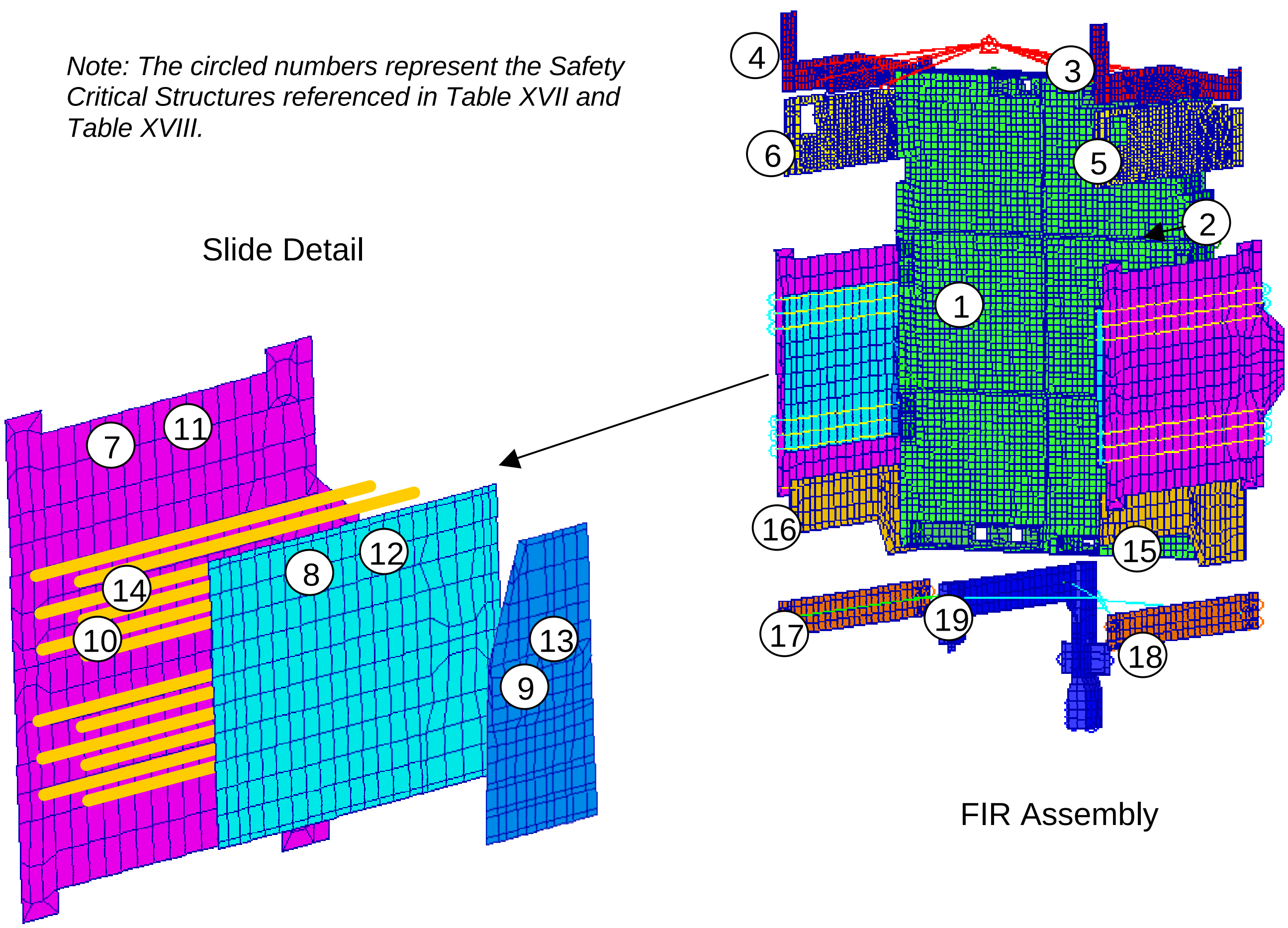


Figure 7. Fluids Integrated Rack Safety Critical Structures

9.3 Fasteners

The Safety Critical Fasteners are shown in Figure 8. In general, fasteners were modeled in the FEA using RBE2 elements. All ¼-28 fasteners interfacing with the ISPR rack posts were modeled using three spring elements; one element in the axial direction (stiffness was 5e6 lbs/in) and the other two elements in the shear directions (shear stiffness was 5e5 lbs/in in both directions). These spring elements would effectively simulate the fasteners flexibility at these bolted connections. (Comment: It was noted that bolted connections throughout Boeings ISPR Model were represented using spring elements.)

The fastener analysis neglected frictional resistance such that the fastener would be conservatively loaded by the full shear load. In addition, the fastener shear margins of safety were conservatively determined using the smaller threaded tensile area (A_t) rather than the larger fastener shank area (A_s).

Linear static analyses were performed on the FIR model to extract maximum fastener loads using the 24 lift-off load cases from Table XVI. Margins of safety were determined using the conservative fastener loads shown in Table XIX. Maximum tensile and maximum shear loads were conservatively combined to a single fastener within its group independent of the specific load case and fastener location (For example, Fastener #2 in Group 1 had a maximum tensile load at Load Case 8 and Fastener #4 in group 1 had a maximum shear load at Load Case 15. These maximum loads would be conservatively applied and combined to a single fastener within group 1 as if they occurred at one specific load case.)

A spreadsheet program (MS Excel) was used to calculate the Fastener Margins of Safety based on NSTS 08307. All of the safety critical fasteners were determined to have positive safety margins as shown in Table XX. Appendix C.3 provides the complete definitions, formulas, and calculations used in the fastener analysis.

9.4 Common FCF Hardware

Common FCF hardware such as the ATCU, Doors, ECS Brackets, EPCU/IOP Support Brackets and slides are currently being designed and developed. Structural analyses of these common systems will be performed and reported at a date TBD.

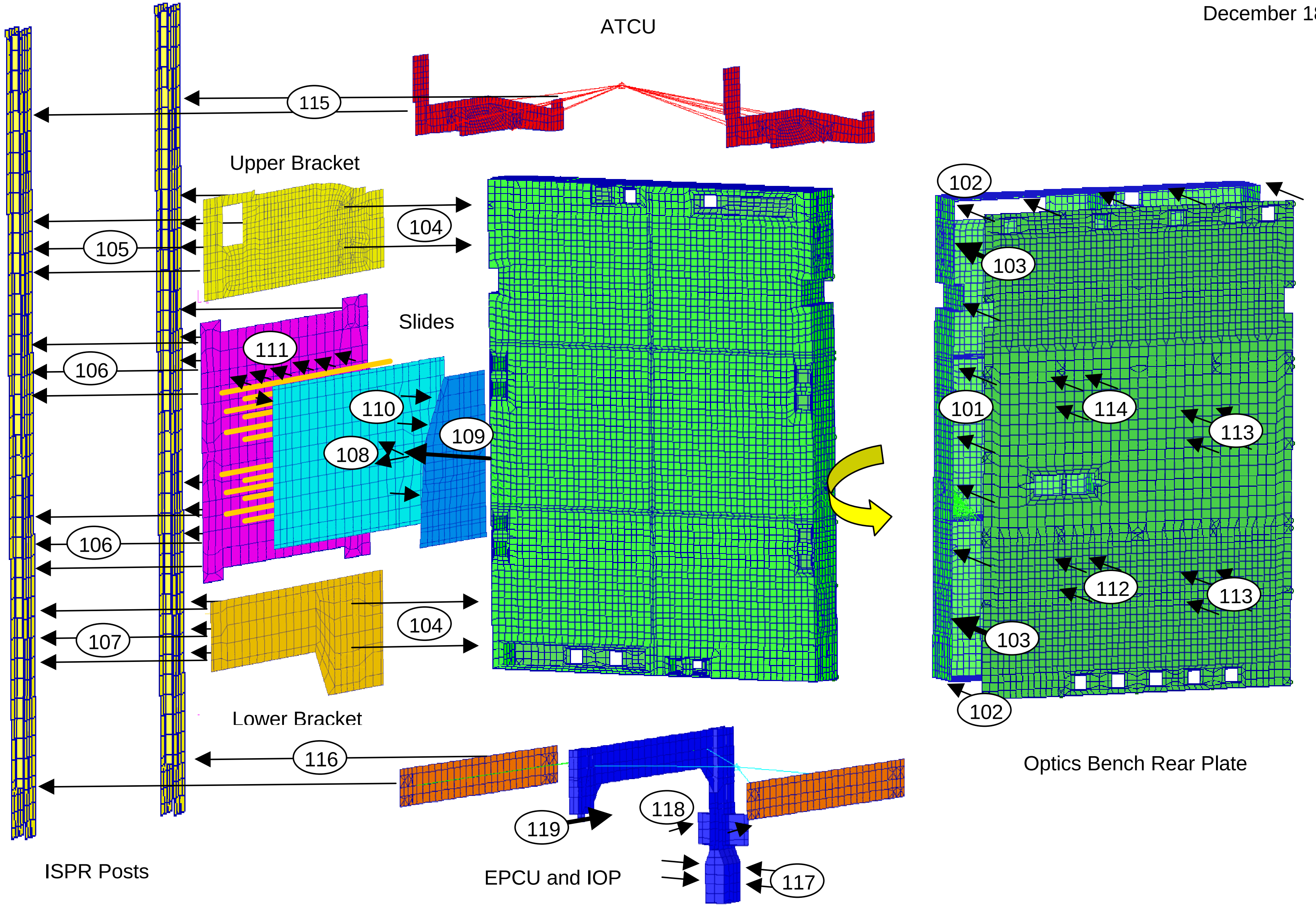


Figure 8. FIR Safety Critical Fasteners

Table XVII. Fluids Integrated Rack Safety Critical Structures Stress Summary

SCS	SCS No.	Maximum Principal Stress (+psi)	Element/ Load case-Plane	Minimum Principal Stress (-psi)	Element/ Load case-Plane	Maximum Shear Stress (psi)	Element/ Load case-Plane
Optics Bench Assembly							
Optics Bench	1	**13031**	232021 /8-Z1	**12227**	200537 /8-Z1	**6936**	203324 /6-Z2
Rear Plate	2	**22845**	211484 /7-Z1	**23112**	211503 /7-Z1	**11556**	211503 /7-Z1
Right ATCU Plate	3	**16616**	230100 /14-Z1	**18296**	228780 /6-Z1	**9636**	228772 /5-Z1
Left ATCU Plate	4	**18012**	230117 /8-Z1	**16536**	230117 /13-Z1	**9505**	230117 /8-Z1
Upper Right Support Plate	5	**29584**	230109 /8-Z1	**26463**	230109 /8-Z2	**14792**	230109 /8-Z1
Upper Left Support Plate	6	**21809**	230716 /9-Z1	**23484**	231330 /6-Z1	**12297**	231330 /6-Z1
Right Slide Assembly							
Outer SS Skin	7	**51368**	213398 /13-Z1	**52434**	213398 /8-Z1	**26217**	213398 /8-Z1
Inner SS Skin	8	**10663**	214021 /8-Z2	**9160**	214002 /1-Z1	**5332**	214021 /8-Z2
Aluminum Stiffening Plate	9	**5858**	214261 /8-Z2	**5787**	214261 /8-Z2	**2929**	214261 /8-Z2
Slides	10	**1000**	1000 /4	**1000**	1000 /4	**1000**	1000 /4
Left Slide Assembly							
Outer SS Skin	11	**47760**	212356 /9-Z1	**47760**	212356 /16-Z1	**23880**	212356 /9-Z1
Inner SS Skin	12	**12587**	212988 /4-Z2	**14868**	212988 /5-Z2	**7434**	212988 /5-Z2
Aluminum Stiffening Plate	13	**8136**	213228 /5-Z1	**8019**	213228 /5-Z1	**4068**	213228 /5-Z1
Slides	14	**1000**	1000 /4	**1000**	1000 /4	**1000**	1000 /4
Bottom Right Support Plate	15	**19082**	208873 /7-Z1	**20193**	208873 /7-Z2	**10097**	208873 /7-Z2
Bottom Left Support Plate	16	**18562**	209021 /6-Z1	**17816**	209021 /6-Z2	**9281**	209021 /6-Z2
IOP/EPCU Support Hardware							
Left Support	17	**12302**	232652 /7-Z1	**12487**	232653 /7-Z2	**6243**	232653 /7-Z2
Right Support	18	**11671**	232952 /6-Z1	**11472**	232951 /6-Z2	**5835**	232952 /6-Z1
Center Support	19	**19550**	231849 /13-Z2	**19550**	231849 /12-Z2	**10352**	231849 /12-Z2

Table XVIII. Fluids Integrated Rack Safety Critical Structures Margins of Safety

	SCS No.	MS Max Tensile Yield	MS Max Tensile Ultimate	MS Max Compressive Yield	MS Max Compressive Ultimate	MS Shear Ultimate
Factor of Safety		**1.25**	**2.0**	**1.25**	**2.0**	**2.0**
Optics Bench Assembly						
Optics Bench	1	**1.15**	**0.61**	**1.29**	**0.72**	**0.95**
Rear Plate	2	**1.00**	**0.49**	**0.94**	**0.47**	**0.64**
Right ATCU Plate	3	**1.74**	**1.05**	**1.45**	**0.86**	**0.97**
Left ATCU Plate	4	**1.53**	**0.89**	**1.71**	**1.06**	**1.00**
Upper Right Support Plate (Figure 9***)***	5	**0.54**	**0.15**	**0.69**	**0.28**	**0.28**
Upper Left Support Plate	6	**1.09**	**0.56**	**0.91**	**0.45**	**0.55**
Right Slide Assembly						
Outer SS Skin	7	**0.95**	**0.69**	**0.27**	**0.66**	**0.81**
Inner SS Skin	8	**8.38**	**7.16**	**6.25**	**8.50**	**7.91**
Aluminum Stiffening Plate	9	**3.78**	**2.58**	**3.84**	**2.63**	**3.61**
Slides	10	**19.80**	**35.50**	**17.40**	**35.50**	**24.00**
Left Slide Assembly						
Outer SS Skin	11	**1.09**	**0.82**	**0.39**	**0.82**	**0.99**
Inner SS Skin	12	**6.94**	**5.91**	**3.47**	**4.85**	**5.39**
Aluminum Stiffening Plate	13	**2.44**	**1.58**	**2.49**	**1.62**	**2.32**
Slides	14	**19.80**	**35.50**	**17.40**	**35.50**	**24.00**
Bottom Right Support Plate	15	**1.39**	**0.78**	**1.22**	**0.68**	**0.88**
Bottom Left Support Plate	16	**1.46**	**0.83**	**1.51**	**0.91**	**1.05**
IOP/EPCU Support Hardware						
Left Support	17	**2.71**	**1.76**	**2.59**	**1.72**	**2.04**
Right Support	18	**2.91**	**1.91**	**2.91**	**1.96**	**2.26**
Center Support	19	**1.33**	**0.74**	**1.29**	**0.74**	**0.84**

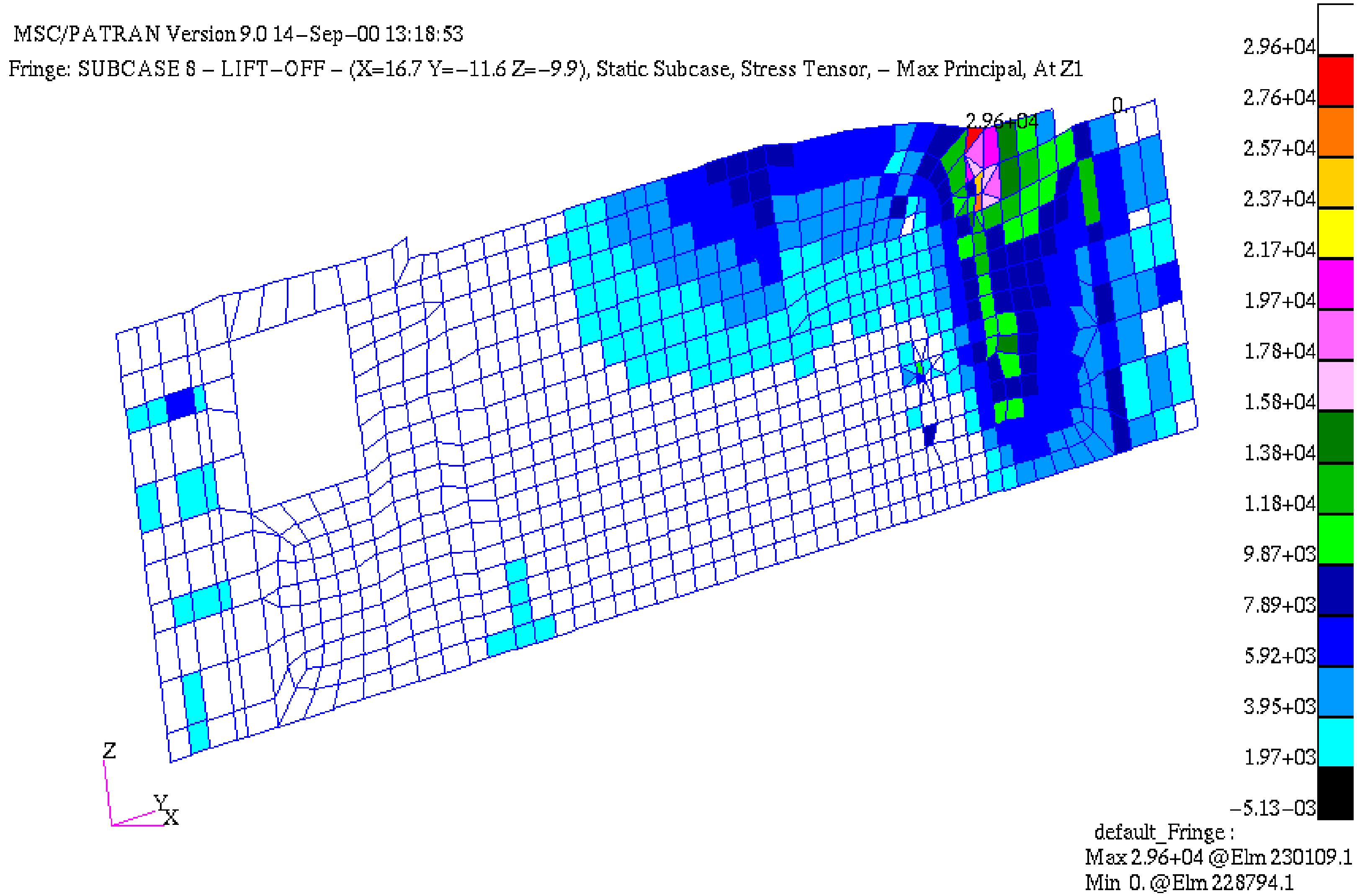


Figure 9. Stress Plot of the Upper Right Support Plate – Load Case 8

Table XIX. Fluids Integrated Rack Safety Critical Fastener Loads

Safety Critical Fasteners	-	-	Load Parameters		
- Fastener Location	- Matl, Size, Type, Qty	- SCS No.	*axial* Pe lbs	*comp* Pe lbs	shear Ps lbs
Optics Bench Assy.					
Optics Bench Rear Plate to Optics Bench - STANDARD	A286 1/4-28 to Locking Insert	101	619	619	1273
Optics Bench Rear Plate to Optics Bench -CORNERS	A286 5/16 -24 to Locking Insert	102	619	619	1940
Optics Bench Rear Plate to Optics Bench -SHEAR PINS	A286 1/4 Shear Pins	103	na	na	2793
Optics Bench Assy. To Support Plates	A286 5/16 to Locking Insert	104	2431	2851	1504
Top Support Plates to ISPR Posts	A286 1/4-28 to ISPR Floating Nut	105	1829	2193	1063
Slide Support Plates to ISPR Posts	A286 1/4-28 to ISPR Floating Nut	106	342	349	912
Bottom Support Plates to ISPR Posts	A286 1/4-28 to ISPR Floating Nut	107	1436	1674	1336
Pivot Fasteners on OB to Slides	A286 1/4-28	108	703	822	332
Pivot Shaft	300 Series Shaft (in Shear only)	109	243	289	2126
Slide Assy.					
Inner Slide Shell to Stiffener Plate	A286 1/4-28 to Locking Insert	110	569	360	509
Slides to Sheet Metal	A286 1/4-28 to Locking Insert	111	381	445	155
Subsystems					
FASP to Optics Bench Rear Plate	A286 1/4-28 to Locking Insert	112	481	531	1429
IPSU to Optics Bench Rear Plate	A286 1/4-28 to Locking Insert	113	453	443	1527
PIFASP to Optics Bench	A286 1/4-28 to Locking Insert	114	623	625	1449
ATCU Assy.					
ATCU Support Plates to ISPR Posts	A286 1/4-28 to ISPR Floating Nut	115	930	1088	695
IOP/EPCU Assy.					
Support Rails to Posts	A286 1/4-28 to ISPR Floating Nut	116	953	1130	1590
Center Rail Support Rear Fasteners	A286 1/4-28 to ISPR Locking Nut	117	101	101	374
Center Rail Support Brackets	A286 1/4-28 to ISPR Locking Nut	118	226	226	384
Center Rail Support Front Fastener	A286 7/16-20 Boeing Proprietary	119	127	127	589

Table XX. Fluids Integrated Rack Safety Critical Fastener Margins of Safety

Safety Critical Fasteners			Summary		*based on NSTS 08307*		
Fastener Location	Matl, Size, Type, Qty	SCS No.	Margins of Safety *Tension* MSu	MSy	*Shear* MSu	*Tens+Shear* MSu	*Joint Sep.* MS
Optics Bench Assy.							
Optics Bench Rear Plate to Optics Bench - STANDARD	A286 1/4-28 to Locking Insert	101	0.56	0.19	0.39	0.13	2.05
Optics Bench Rear Plate to Optics Bench -CORNERS	A286 5/16 -24 to Locking Insert	102	0.59	0.21	0.45	0.18	3.96
Optics Bench Rear Plate to Optics Bench -SHEAR PINS	A286 1/4 Shear Pins	103	na	na	0.14	na	Na
Optics Bench Assy. To Support Plates	A286 5/16 x 24 to Locking Insert	104	0.34	0.08	0.87	0.19	0.44
Top Support Plates to ISPR Posts	A286 1/4-28 to ISPR Floating Nut	105	0.43	0.13	0.66	0.19	0.03
Slide Support Plates to ISPR Posts	A286 1/4-28 to ISPR Floating Nut	106	0.61	0.21	0.93	0.37	4.24
Bottom Support Plates to ISPR Posts	A286 1/4-28 to ISPR Floating Nut	107	0.47	0.15	0.32	0.06	0.32
Pivot Fasteners on OB to Slides	A286 1/4-28 to ISPR Floating Nut	108	0.56	0.19	4.31	0.55	1.64
Pivot Shaft	300 Series Shaft (in Shear only)	109	na	na	1.49	na	Na
Slide Assy.							
Inner Slide Shell to Stiffener Plate	A286 1/4-28 to Locking Insert	110	0.59	0.21	2.47	0.54	2.17
Slides to Sheet Metal	A286 1/4-28 to Locking Insert	111	0.61	0.21	10.38	0.61	3.73
Subsystems							
FASP to Optics Bench Rear Plate	A286 1/4-28 to Locking Insert	112	1.52	0.95	0.23	0.21	1.49
IPSU to Optics Bench Rear Plate	A286 1/4-28 to Locking Insert	113	1.54	0.96	0.16	0.12	1.64
PIFASP to Optics Bench	A286 1/4-28 to Locking Insert	114	1.47	0.92	0.22	0.18	0.92
ATCU Assy.							
ATCU Support Plates to ISPR Posts	A286 1/4-28 to ISPR Floating Nut	115	0.46	0.14	1.54	0.38	1.28
IOP/EPCU Assy.							
Support Rails to Posts	A286 1/4-28 to ISPR Floating Nut	116	1.39	0.88	0.11	0.05	0.22
Center Rail Support Rear Fasteners	A286 1/4-28 to ISPR Locking Nut	117	0.63	0.22	3.72	0.61	18.20
Center Rail Support Brackets	A286 1/4-28 to ISPR Locking Nut	118	0.61	0.22	3.59	0.59	7.58
Center Rail Support Front Fastener	A286 7/16-20 Boeing Proprietary	119	0.64	0.23	8.78	0.63	48.34

10.0 FRACTURE ANALYSIS

10.1 Safe Life Analyses

TBD

10.2 Fail Safe Analyses

A Preliminary Fastener Fail Safe Analysis was performed on the FIR to ISPR interface post fasteners (1/4-28 fasteners, safety critical fastener numbers 105, 106, 107, and 115) and on the optics bench to support plate fasteners (5/16 fasteners, safety critical fastener number 104). Analyses were conducted by assuming failure at the most critically loaded fasteners, (i.e., The highest loaded fastener at each structural component supporting the optics bench.), reapplying the 24 load cases of Table XVI so that the loads will be redistributed into the remaining fasteners, and determining whether the remaining fasteners have positive margin of safety using an ultimate factor of safety of 1.0.

A Preliminary Fastener Fail Safe Analysis was performed on the center rail support front fastener (single 7/16 fastener, safety critical fastener number 119) of the IOP/EPCU Assembly. The analysis checked the redistributed loads and margins of safety for safety critical fasteners numbered 116, 117, and 118.

The Fail Safe fastener loads are shown in Table XXI. The positive Fail Safe margins of safety are shown in Table XXII. The Fail Safe analysis proves there is adequate fastener redundancy and that these fasteners can be classified as Non-Fracture Critical.

Table XXI. Fail Safe Analysis - Fastener Loads

Safety Critical Fasteners			Load Parameters		
Fastener Location	Matl, Size, Type, Qty	SCS No.	*axial* Pe lbs	*comp* Pe lbs	shear Ps lbs
Fail Safe Analysis					
Optics Bench Assy. To Support Plates	A286 5/16 to Locking Insert	104	3033	3557	1519
Top Support Plates to ISPR Posts	A286 1/4-28 to ISPR Floating Nut	105	2252	2686	1076
Slide Support Plates to ISPR Posts	A286 1/4-28 to ISPR Floating Nut	106	434	434	927
Bottom Support Plates to ISPR Posts	A286 1/4-28 to ISPR Floating Nut	107	1374	1624	1273
ATCU Support Plates to ISPR Posts	A286 1/4-28 to ISPR Floating Nut	115	913	1048	935
IOP/EPCU Assy.					
Support Rails to Posts	A286 1/4-28 to ISPR Floating Nut	116	960	1137	1569
Center Rail Support Rear Fasteners	A286 1/4-28 to ISPR Locking Nut	117	134	134	497
Center Rail Support Brackets	A286 1/4-28 to ISPR Locking Nut	118	228	228	380

Table XXII. Fail Safe Analysis - Fastener Margins of Safety

FIR Fastener Analysis-ENG *based on NSTS 08307*

Safety Critical Fasteners			Summary				
Fastener Location	Matl, Size, Type, Qty	SCS No.	Margins of Safety				
			Tension MSu	MSy	*Shear* MSu	*Tens+Shear* MSu	*Joint Sep.* MS
Fail Safe Analysis							
Optics Bench Assy. To Support Plates	A286 5/16 to Locking Insert	104	0.44	NA	2.71	0.41	0.38
Top Support Plates to ISPR Posts	A286 1/4-28 to ISPR Floating Nut	105	0.51	NA	2.28	0.46	0.01
Slide Support Plates to ISPR Posts	A286 1/4-28 to ISPR Floating Nut	106	0.62	NA	2.81	0.59	3.95
Bottom Support Plates to ISPR Posts	A286 1/4-28 to ISPR Floating Nut	107	0.56	NA	1.77	0.47	0.65
ATCU Support Plates to ISPR Posts	A286 1/4-28 to ISPR Floating Nut	115	0.55	NA	2.77	0.52	1.78
IOP/EPCU Assy.							
Support Rails to Posts	A286 1/4-28 to ISPR Floating Nut	116	1.55	NA	1.25	1.03	0.45
Center Rail Support Rear Fasteners	A286 1/4-28 to ISPR Locking Nut	117	0.63	NA	6.10	0.63	16.37
Center Rail Support Brackets	A286 1/4-28 to ISPR Locking Nut	118	0.62	NA	8.28	0.62	9.21

APPENDIX A ACRONYMS AND ABBREVIATIONS

A.1 Scope.

This appendix lists the acronyms and abbreviations used in this document.

A.2 List of acronyms and abbreviations.

ARIS	Active Rack Isolation System
ATCU	Air Thermal Control Unit
CIR	Combustion Integrated Rack
DCM	Diagnostic Control Module
ECS	Environmental Control System
EPCU	Electrical Power Control Unit
FCF	Fluids and Combustion Facility
FE	Finite Element
FEA	Finite Element Analysis
FIR	Fluids Integrated Rack
FOS	Factor of Safety
FSAP	Fluid Science Avionics Package
IOP	Input/Output Processor
IPSU	Image Processing Storage Unit
ISPR	International Standard Payload Rack
ISS	International Space Station
MIL-STD	Military Standard
MPLM	Mini-Pressurized Logistics Module
MS	Margin of Safety
NSTS	National Space Transportation System

PI	Principal Investigator
RVLF	Random Vibration Load Factor
SCS	Safety Critical Structures
TBD	To Be Determined

APPENDIX B DEFINITIONS

B.1 Scope.

This appendix defines special terminology used in this document.

B.2 List of definitions.

NA

APPENDIX C MARGIN OF SAFETY CALCULATIONS

C.1 Scope.

State the scope of this appendix.

C.2 Stress Analysis Details

C.2.1 Component Spreadsheet

A spreadsheet program (MS EXCEL) was used to determine the margins of safety for each of the safety critical structural components based on the principal stresses (checked both maximum and minimum) and Maximum Shear stresses.

Input to this spreadsheet consists of the material allowables for each of the components as well as the maximum element stress value (Principal Stresses, Maximum and Minimum, and Maximum Shear) for each part. Again, the maximum stress is obtained from the internal sorting capability of the PATRAN program. Element centroidal stresses are used in the spreadsheet to obtain the minimum margins of safety in each component.

Factors of safety used in the spreadsheet for the margins of safety calculations are:

Factor of Safety, Yield = 1.25

Factor of Safety, Ultimate = 2.0

The margins of safety for each safety critical structural component are calculated as follows:

$$MS_{yld} = \frac{F_{yld}}{(SF_{yld})(F_{act})} - 1.0$$

With: MS_{yld} = Margin of Safety, Yield Criteria

F_{yld} = Material Allowable Tensile Yield Stress, psi (70^{o} F)

Sf_{yld} = Factor of Safety, Yield, 1.25

F_{act} = Principal Stress for the Component, psi

$$MS_{ult} = \frac{F_{ult}}{(SF_{ult})(F_{act})} - 1.0$$

With: MS_{ult} = Margin of Safety, Ultimate Criteria

F_{ult} = Material Allowable Ultimate Tensile Stress, psi (70^{o} F)

SF_{ult} = Factor of Safety, Ultimate, 2.0

F_{act} = Principal Stress for the Component, psi

$$MS_{shear} = \frac{F_{shear}}{(SF_{ult})(F_{act})} - 1.0$$

With: MS_{shear} = Margin of Safety, Shear Criteria

F_{shear} = Material Allowable Ultimate Shear Stress, psi (70^{o} F)

SF_{ult} = Factor of Safety, Ultimate, 2.0

F_{act} = Maximum Element Shear Stress for the Component, psi

C.3 Fastener Analysis Details

C.3.1 Fastener Analysis

The fastener analyses on all of the Safety Critical Structure (SCS) bolted connections were performed with the use of a spreadsheet program. The spreadsheet was generated using EXCEL. The calculations preformed in the spreadsheet follow the guidelines of NSTS 08307 and MSFC-STD-486B.

C.3.2 Bolt Preload

The bolt preload is put in via the fastener torque. The preloads used in this analysis are determined by the following equation from NSTS 08307;

$$P_{nom} = \left(\frac{T}{KD}\right)(1.0 \pm m)$$

T	=	Torque (in-lbs.)	
D	=	Nominal Diameter	
K	=	Nut Factor	0.20 (Unlubricated threads)
			0.15 (Lubricated threads)

or

From MSFC-STD-486B; Torque fastener to 65% of tensile yield strength.

$$(T/KD) \quad = \quad 0.65\,(F_{ty}\ A_t)$$

Preload uncertainty factor. (From NSTS 08307 for hand operated torque wrench with a lubricated surface.)

μ = 0.25

Minimal tensile area located in the fastener threads. (D = basic minor diameter, N = No. of threads/in.)

A_t = $0.7854\,(D - 0.9743/N)^2$

$$P_{\max} = (0.65 F_{ty} A_t)(1.0 + m) + P_{th}$$

The maximum and minimum preloads are determined from the following equations:

P_{th} = Thermal effect

$$P_{\min} = (0.65 F_{ty} A_t)(1.0 - m) - P_{th} - P_{relax}$$

P_{relax} = Preload lost due to joint relaxation. Approximated as 5% of P_{max}

The fastener material properties are used to determine the preload in the joint for all connections using inserts. The material properties used in this analysis are shown in Section 4.0 of this report.

C.3.3 Fastener Axial Load

The total axial load in the fastener consists of the preload obtained by the initial torque plus the externally applied load (obtained from the finite element results). This total axial bolt load, P_b, is obtained from the following equation that is contained in the fastener spreadsheet:

$$P_b = P_{\max} + (SF)(n)(f)P_{ext}$$

P_{ext}= Externally applied load (From FEA analysis, either single point constraint forces at main mounting fasteners or multipoint constraint forces at remaining fasteners.)

SF = Safety Factor (2.0 for Ultimate Strengths; 1.25 for Yield Strengths)

n = Loading Plane Factor (Accounts for the location of the load induced into the joint.)

n = 0.50 @ Joint Separation-Conservative

n = 1.0 @ Tensile Applications - Conservative

ϕ = Joint Stiffness Factor. Relates the stiffness of the joint to the stiffness of the fastener.

The Joint Stiffness Factor, ϕ , is defined by the following:

$$f = \frac{K_b}{K_b + K_m}$$

With: K_b = Fastener Stiffness, (lb/in)

K_m = Member Stiffness, (lb/in)

The Fastener Stiffness is obtained by the equation:

$$K_b = \frac{A E_b}{L}$$

With:

A = Bolt Cross-Sectional Area, (Spreadsheet uses diameter of 0.164, 0.190 or 0.250)

E_b = Young's Modulus for the fastener

L = Fastener/Joint length. (L =$\text{Thickness}_{\text{member 1}}$ + $\text{Thickness}_{\text{member 2}}$ + $\text{Thickness}_{\text{member 3}}$ + ...)

The Equivalent Member Stiffness is obtained by the equation:

$$K_m = \frac{1}{\frac{1}{K_{memb}}1 + \frac{1}{K_{memb}}2 + \frac{1}{K_{memb}}3}$$

The Member Stiffness is calculated as follows;

$$K_{memb} = \frac{\pi \; E_j \; d}{\ln \dfrac{5 \; (L + 0.5 \; d)}{(L + 2.5 \; d)}}$$

Where: E_j = Young's Modulus of the joined member.

d = Fastener basic minor diameter.

L = Member thickness

C.3.4 Fastener Strength Criteria (Margins of Safety)

Margins of Safety (MS) calculations are performed on the fasteners in the package for the following categories:

1. Bolt - Yield (Tensile) and Ultimate (Tensile, Shear)
2. Separation of the Joint. (For Information Only at Non Pressure Joint)
3. Bearing on the Members of the Joint
4. Shear Tear Out on the Members of the Joint

The following equations determining the margins of safety for the fasteners are based on NSTS 08307 and are all contained in the fastener spreadsheet.

C.3.4.1 Fastener - Tension, Yield

$$MS_{tyld} = \frac{(F_{bty})(A_t)}{P_b} - 1.0$$

With: F_{bty} = Yield Strength of Fastener, (ksi)

A_t = Minimum Tensile Area of Fastener, (in^2)

P_b = Total Axial Fastener Load, FEM + Preload (lbs)

C.3.4.2 Fastener - Tension, Ultimate

$$MS_{tult} = \frac{(F_{btu})(A_t)}{P_b} - 1.0$$

With: F_{btu} = Ultimate Tensile Strength of Fastener, (ksi)

C.3.4.3 Fastener - Shear, Ultimate

$$MS_{sult} = \frac{(F_{bsu})(A_s)}{(V_{\max})(SF)} - 1.0$$

With: F_{bsu} = Ultimate Shear Strength of Fastener, (ksi)

A_s = Shear Area, (Spreadsheet assumes shear across threads, ie. A_s=A_t)

V_{max} = Resultant Shear Fastener Load, FEM (lbs)

SF = Safety Factor, (For Ultimate Condition = 2.0)

C.3.4.4 Fastener - Combined Tension and Shear, Ultimate

$$MS_{cult} = \frac{1.0}{\sqrt{\left(\frac{1}{MS_{tult} + 1.0}\right)^2 + \left(\frac{1}{MS_{sult} + 1.0}\right)^3}} - 1.0$$

C.3.4.5 Fastener/Joint - Separation (For Information Only)

$$MS_{sep} = \frac{P_{\min}}{(SF_{sep})(1.0 - (n)(f))(P_{ext})} - 1.0$$

With:

SF_{sep} =Factor of Safety for Separation **(**For structural applications=1.2, for pressure applications=1.4) n = Loading Plane Factor, (n = 0.5 for all separation margins of safety calculations.)

C.3.4.6 Gap

$$GAP = [(1.0-n(\phi))*P_{ext}*P_{min}]/(K_m*\phi)$$

With:

n = Loading Plane Factor, (The fastener spreadsheet conservatively has **n = 0.5** for all separation margins of safety calculations.) This will give a larger Gap.

C.3.4.7 Bending Moment Due to Joint Separation

$$MA = GAP * V_{max}$$

C.3.4.8 Allowable Bending Moment

$$M_{ult}=F_{btu}*((\pi*D^3)/16)$$

With:

D = Minimum tested tensile diameter of Fastener.

C.3.4.9 Bending Margin of Safety

$$MS_{ben}=M_{ult}/(MA*SF)$$

C.3.4.10 Combined Loading - Tension, Bending, and Shear, Ultimate

$$Ms_{cult} = 1.0/\{[(1/(MS_{tult}+1.0)+(1/(MS_{ben}+1.0)]^2+(1/(MS_{sult}+1.0)^3\}^{0.5}-1.0$$

C.3.5 Joint Modes of Failure (Margins of Safety)

The members or plates joined by the fasteners are analyzed for potential bearing at the fastener as well as shear tear-out of the plates. These margin of safety calculations are contained in the fastener spreadsheet. The Table X lists the material properties used as input to the spreadsheet program.

C.3.5.1 Joint - Bearing, Ultimate

$$MS_{bear} = \frac{(F_{bru})(D)(t)}{(SF)(V_{\max})} - 1.0$$

With:

F_{bru}	=	Bearing Ultimate Strength of Joined Member
D	=	Diameter of the fastener
t	=	Thickness of the joined plate
SF	=	Safety Factor, (For Ultimate Condition = 2.0)
V_{max}	=	Resultant Shear Fastener Load, FEA Analysis (lbs)

C.3.5.2 Joint - Shear Tear Out, Ultimate

$$MS_{tear} = \frac{(2.0)(F_{su})(t)(e)}{(SF)(V_{\max})} - 1.0$$

With: F_{su} = Ultimate Shear Strength of Joined Member

e = Distance from bolt center line to the edge of the plate. The analysis conservatively used a distance of (e-D/2).

C.3.6 Fastener Spreadsheet: Input/Output

The formulas presented in this Appendix are all included into the EXCEL spreadsheet for fasteners. A summary of the inputs and outputs of the spreadsheet are:

C.3.6.1 Fastener Spreadsheet Output

Maximum and Minimum Fastener Preload

Margins of Safety for:

Bolt - Yield (Tensile) and Ultimate (Tensile, Shear)

Separation of the Joint

Bearing on the Members of the Joint

Shear Tear Out on the Members of the Joint

C.3.6.2 Fastener Spreadsheet Input

Maximum External Axial and Shear Fastener Loads (From NASTRAN Output)

Material Properties and Allowables for Fasteners, Joined Members (From Section 4.0)

Fastener Diameters, Areas, Joined Member Thickness (From Part Drawings)

Safety Factors (From Section 3.5)